ISBI 2025

2025 IEEE International Symposium on Biomedical Imaging

April 14-17, 2025 | Houston, TX, USA

Accurate 3D Medical Image Segmentation with Mambas

K. Marchesini, L. Lumetti, V. Pipoli, E. Ficarra, C. Grana, F. Bolelli

AImage Lab
University of Modena and Reggio Emilia

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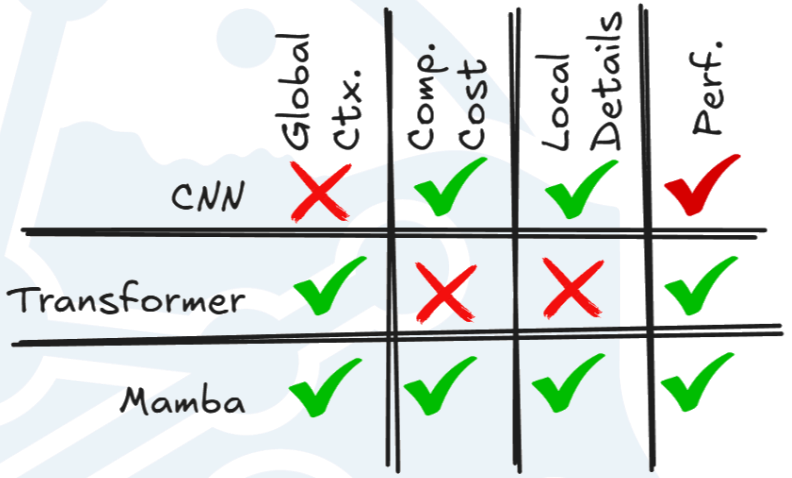
Motivation

- Voxel-level **3D medical image segmentation** plays a crucial role in clinical applications such as surgical planning and diagnosis:
  - CNNs are effective in capturing local details;
  - Transformer-based models can capture global context but at high computational cost.



- We **investigate the effectiveness of Mamba** which achieves long-range sequence processing with **linear complexity** while keeping voxel-level details.
- Specifically, we examined the impact of **modeling directionality** on one or more axes, since Mamba works on 1D sequences.

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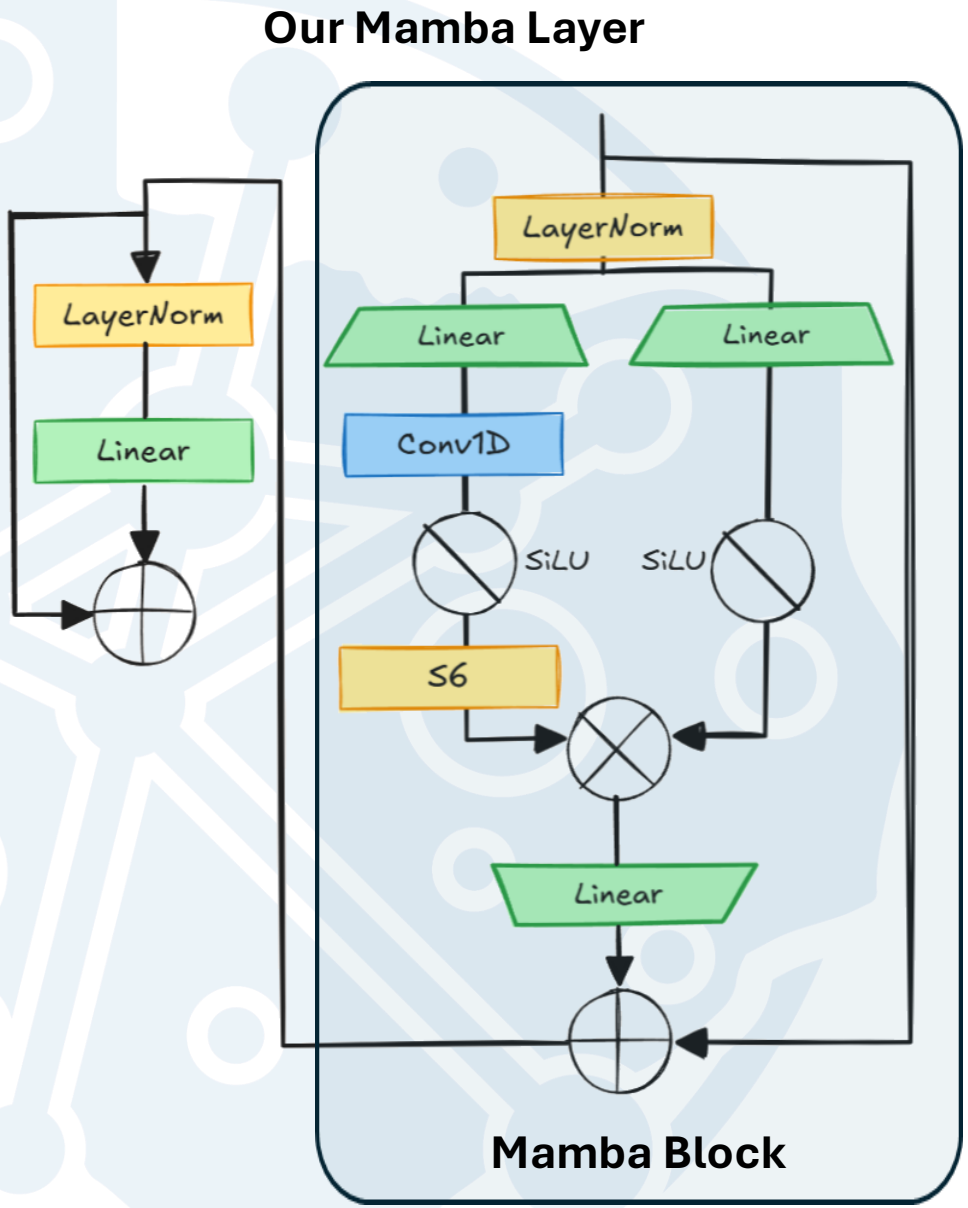
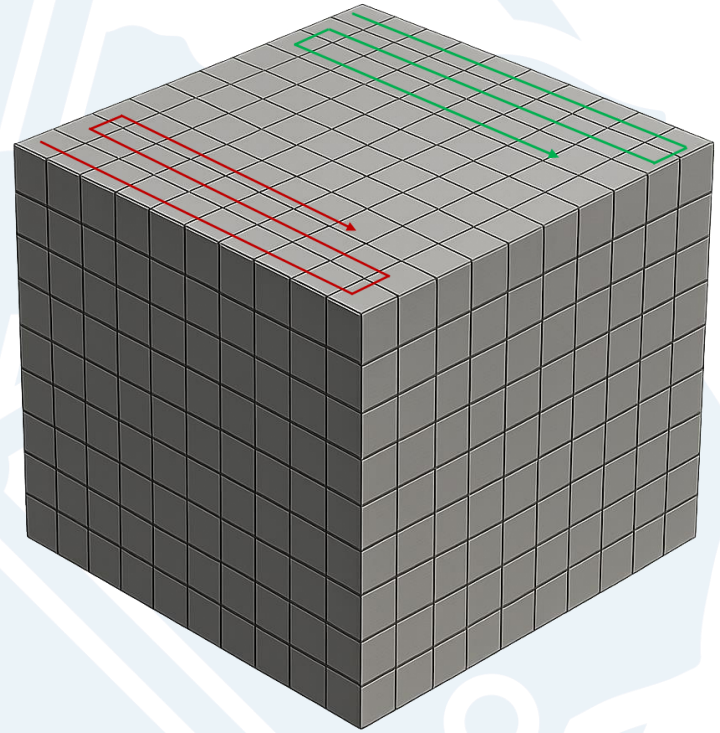
Mamba

- A **linear-time sequence model** employed to represent dynamic systems by mapping inputs to latent states and outputs.
- Mamba's efficient implementation mixes **structured state space models** (SSMs) with linear projections and convolutions for sequence modeling.
- We **design** a **Mamba layer** including an additional LayerNorm, an MLP head, and a residual connection.



Limitations

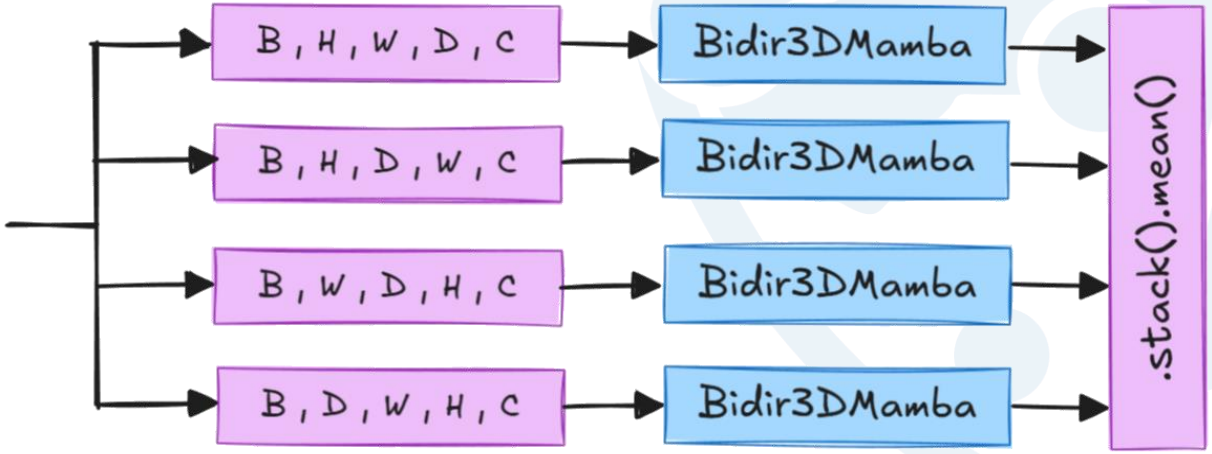
- Unfortunately, Mamba is **not permutation invariant**.
- To process 3D volumes with Mamba, **spatial dimensions are flattened into 1D** sequences, but the dilemma is: what is the best axis order?
- We experimented **3 variants**:
  - **Unidirectional**
  - **Bidirectional**
  - **Multidirectional**



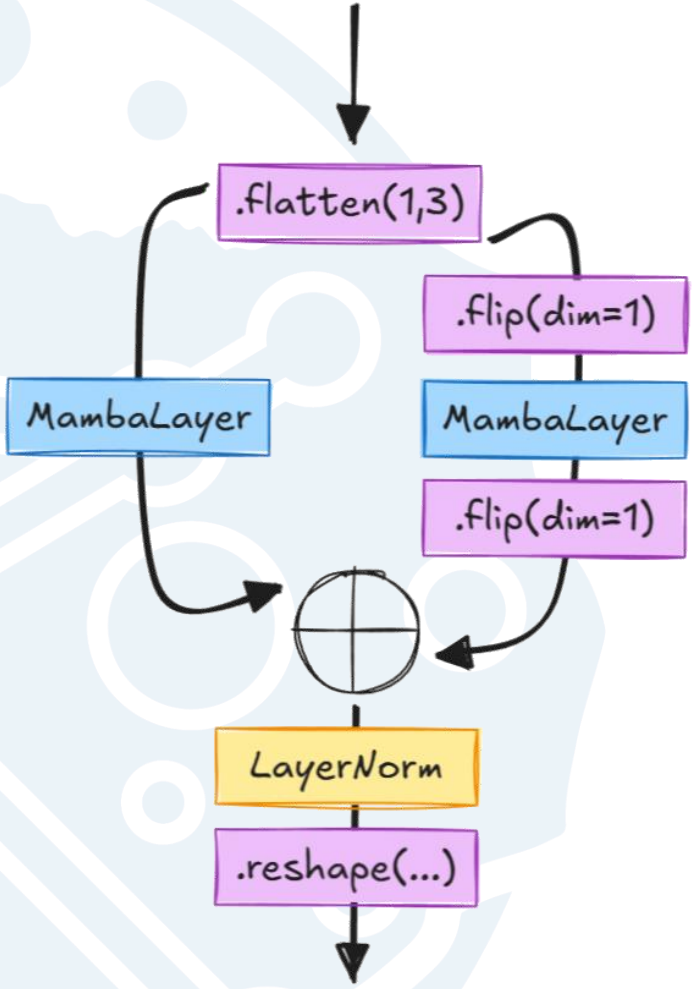
3D Volume

Bidirectional *vs.* Multidirectional

- **Bidirectional** processes data in both forward and backward directions, ensuring that each voxel receives context from all other voxels in at least one of the two directions.
- With **multidirectional** we propose to process multiple sequential arrangement.



Multidirectional



Bidirectional

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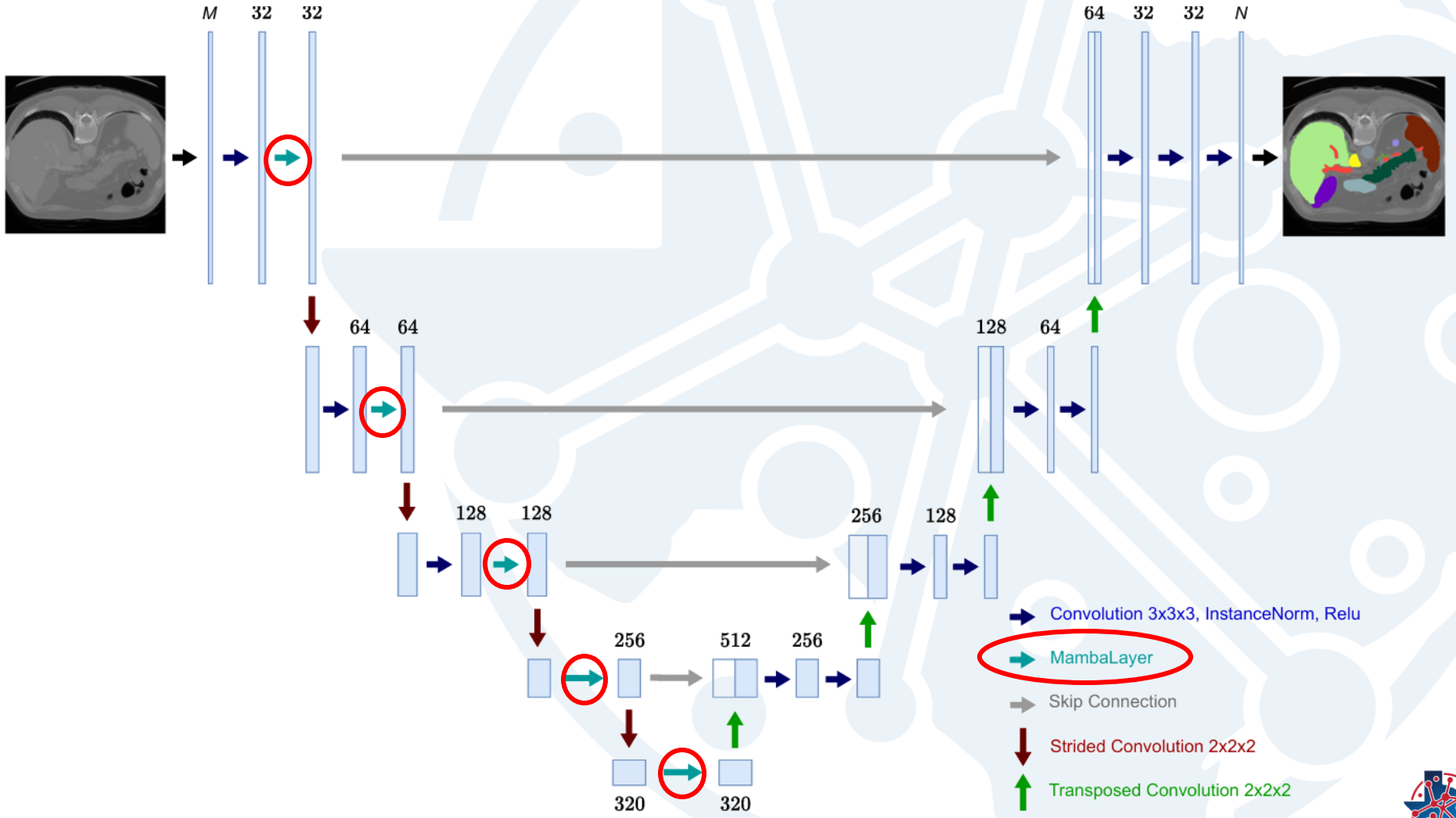
Integrating Mamba within UNet



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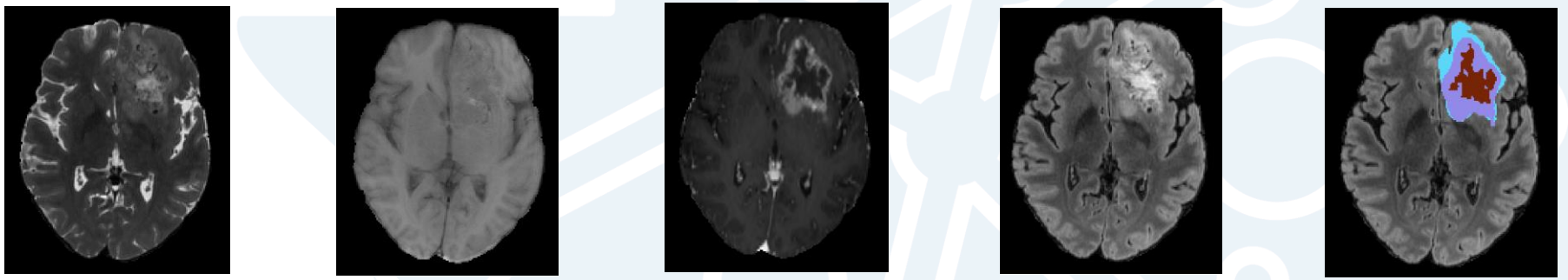
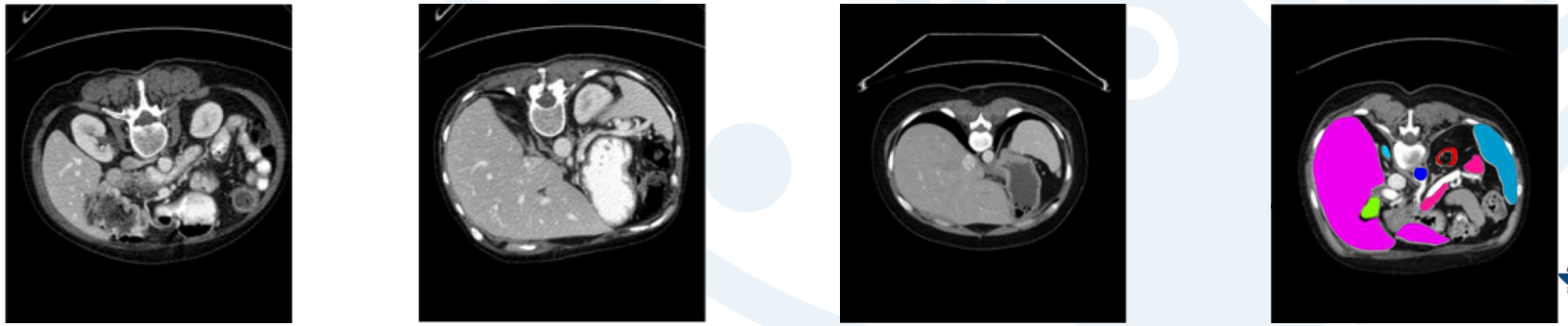
Datasets

- We conducted experiments using two different well- known datasets:
  - **MSD BrainTumor** from the Medical Segmentation Decathlon



  - The **Synapse Multi-organ** segmentation dataset



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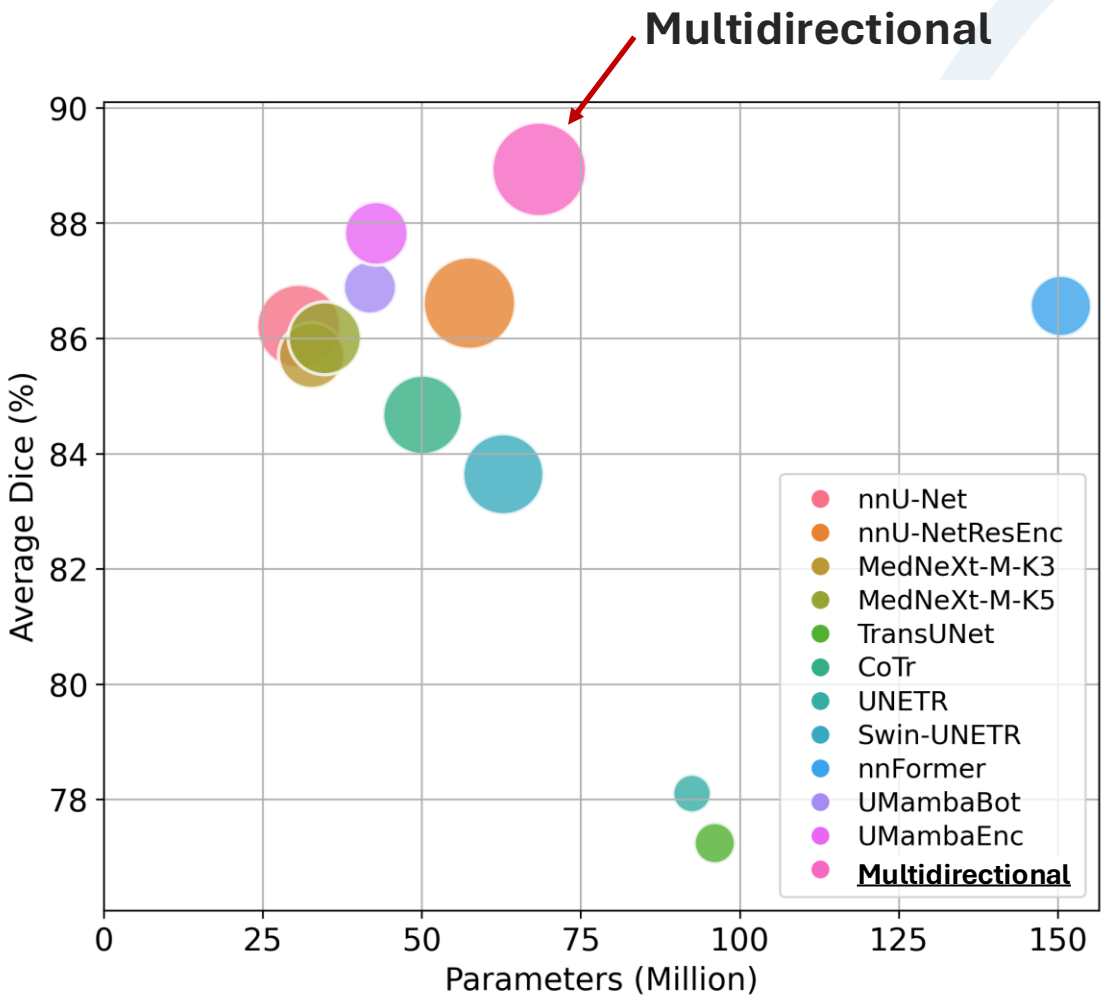
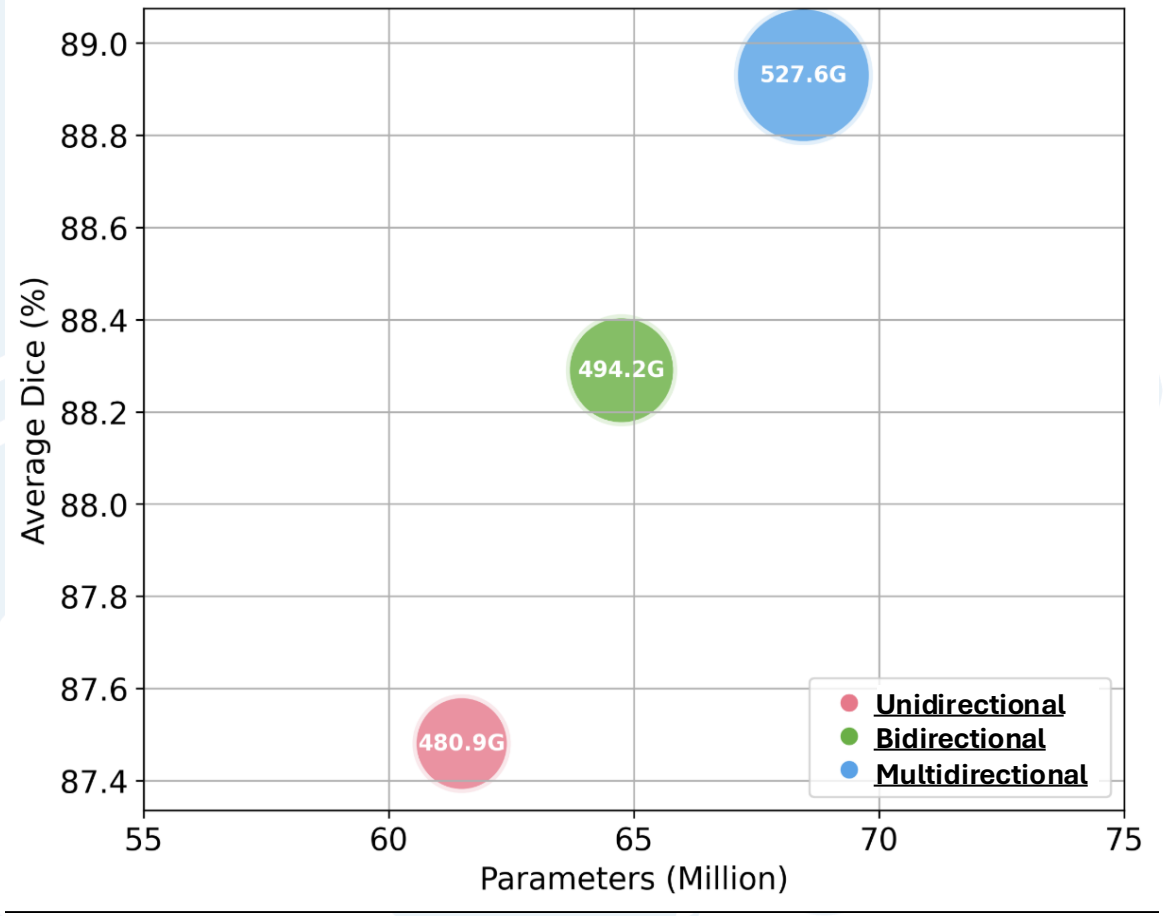
Results (Synapse)





* Circle size indicates GFLOPS.

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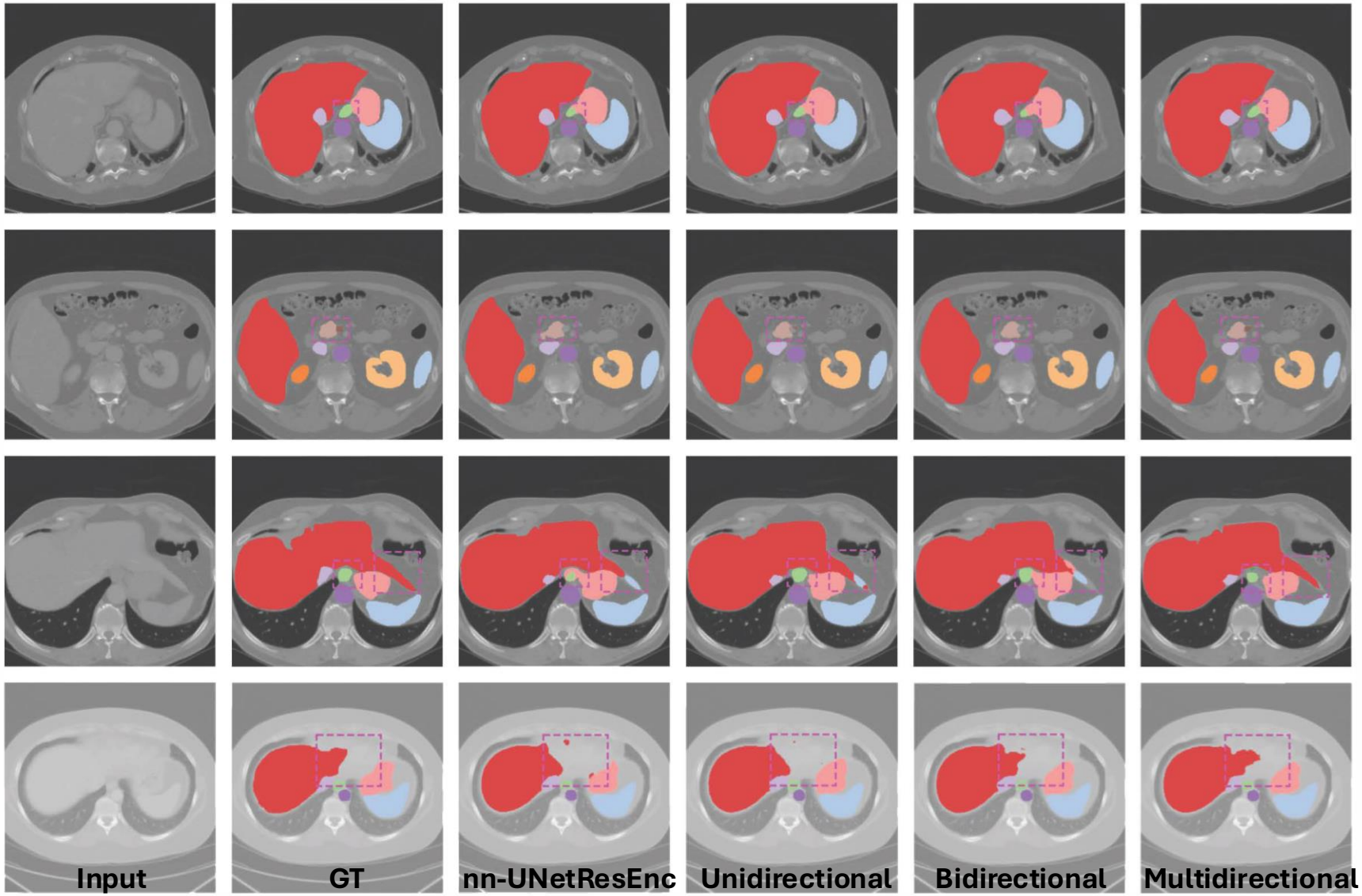
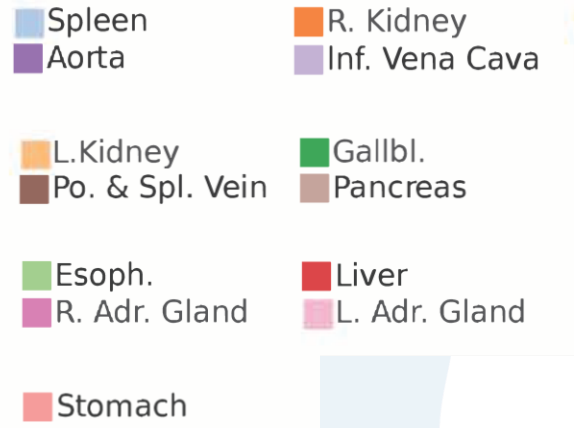
Visualization (Synapse)





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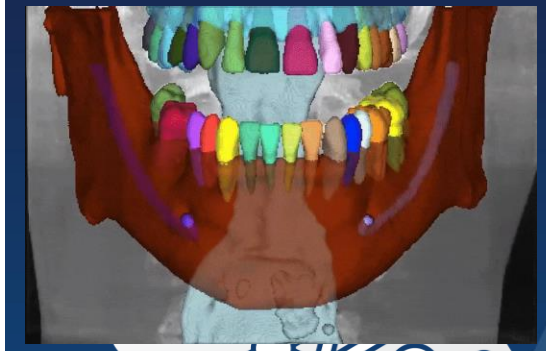

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